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# Ecosystem Services and Reallocation Choices: A Framework for Preserving Semi-Arid Regions in the Southwest

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**Abstract:** Conservation of freshwater systems is critical in the semi-arid Southwest where ground water and flood regimes strongly influence the abundance, composition, and structure of riparian vegetation. At the same time, these systems are in high demand for competing human uses. To address this conflict, natural scientists must evaluate how anthropogenic changes to hydrologic regimes alter ecological systems. A broad foundation of natural science information is needed for ecological valuation efforts to be successful. This paper examines how to incorporate hydrologic, vegetation, avian, and economic models into an integrated framework to determine the value of changes in ecological systems. We have developed a hydro-bio-economic framework for the San Pedro River Region in Arizona, and we are developing a similar framework for the Middle Rio Grande of New Mexico. Distinct valuation studies are being conducted for each site with benefit-transfer tests between the sites.
**Keywords:** *ecological valuation, ecosystems, integrated modeling*

Conservation of fresh water systems is a paramount issue in the semi-arid Southwestern U.S. (Department of Interior 2005). In these systems, ground water, surface water and flood regimes strongly influence the abundance, composition, and structure of riparian (streamside) vegetation, diversity and abundance of avian populations, and thus overall quantity and quality of system attributes and ecosystem services. Over time, these systems (Zekster et al. 2005) have been degraded by anthropogenic activities and, more recently, are threatened by climate change (Stromberg et al. 2007, Serrat-Capdevila et al. 2007, Alley et al. 2002).

For water reallocation efforts to succeed in preserving these systems, a stakeholder community and/or policy maker requires a clear understanding of the management options available and a means to evaluate these options. Management options can be controversial, especially when the reallocation of existing water rights is required. One potentially effective approach is a Decision Support System, a class of interactive computerized information systems that support decision-making activities (Power 2002). For water management where ecosystem services are part of the decision-making criteria, a decision support system should have the capability of evaluating management options through the use of a series of coupled physical and ecological models that generate ecosystem service outputs. These outputs can then be reflected as monetized societal values for purposes of analyzing management options. However, ecosystem service values generally remain unknown relative to market values for goods and services.

A primary focus of this paper is the value of ecosystem services and how they are derived from a broad base of scientific information. A central tenet of our efforts is that ecosystem values are appropriately driven by sound scientific information

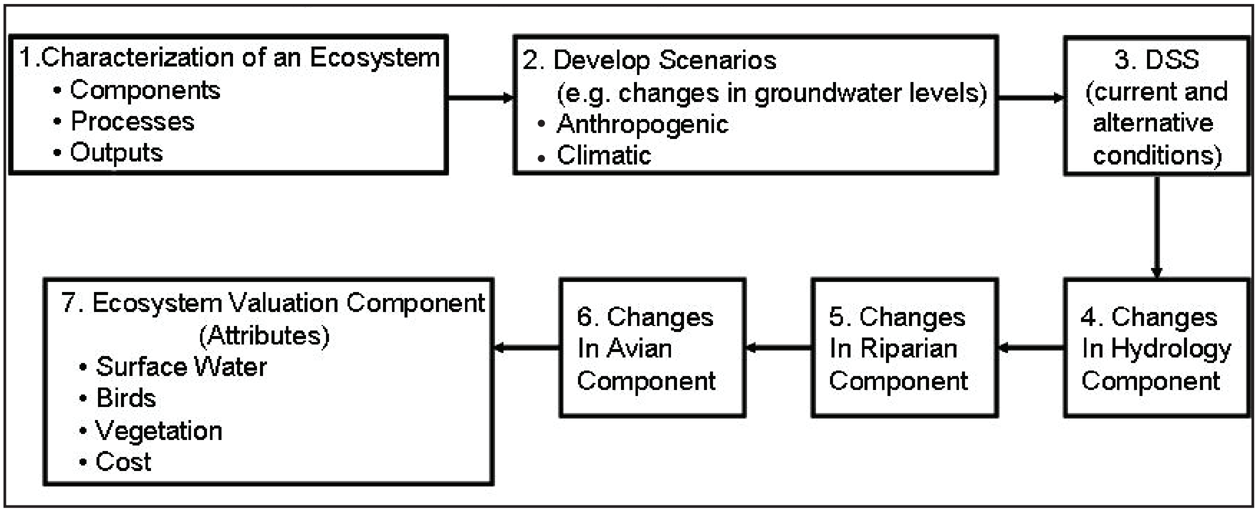


**Figure 1.** How to represent ecosystem services for valuation.

and thus values and sound science are inextricably linked. Valuation studies are typically conducted in the absence of integrated science information either because (1) targeted scientific research on the topic of interest is lacking, or (2) scientific studies that do exist have not been adequately designed to directly inform the valuation questions. We summarize previous scientific studies and present an approach in which ecosystem values are appropriately driven by these studies, and can feed back into a decision support system as a potential framework to help decision makers. We also focus on the process of transferring these values to other semi-arid areas, a key gap in our ability to use science and ecological valuation to help guide management in the region. Finally, in the conclusion, we touch upon the issue of integration of these values back into a decision support system for purposes of evaluating management options.

Our starting point is an existing web-based decision support system that was developed with the Upper San Pedro Partnership (Yalcin and Lansey 2004).[1] Our approach is summarized in Figure 1. The initial step, as detailed in Box 1, is to characterize the ecosystem. This requires an understanding of the components, processes within the system and its outputs. It is the outputs that are of central interest for valuation of ecosystems services. The next step (Box 2) is to develop scenarios. While restoration is a first and central goal in many systems, this represents only the beginning, not the end. Preservation of these systems in the face of dynamic climatic and anthropogenic effects is an important public policy issue. In the case of the San Pedro effort, we focus on ground water changes resulting from various anthropogenic changes. The third step (Box 3) is the coupled model of the physical and biological systems whose relationships are represented, often in simplified form, within the Decision Support System. This represents what might be termed "current conditions" of the overall system representing the understanding of the systems components and their interrelationships. The fourth step is to introduce the scenarios (Box 2) into the decision support system (Box 3) to generate prospective changes to the ecosystem. In this case, we are interested in the changes to the hydrology, riparian, and the avian components (Boxes 4, 5, 6). This series of modeling steps provides the scientifically-based information necessary for the ecosystem valuation exercise.

## San Pedro Riparian National Conservation Area (SPRNCA)

On November 18th, 1988, Congress designated 40 miles of the Upper San Pedro River as a Riparian National Conservation Area (SPRNCA). The primary purpose for this designation was to protect and enhance the desert riparian ecosystem, a rare remnant of what was once an extensive network of similar riparian systems throughout the Southwest. The SPRNCA contains nearly 57,000 acres of public land and is home to 84 species of mammals, 14 species of fish, 41 species of reptiles

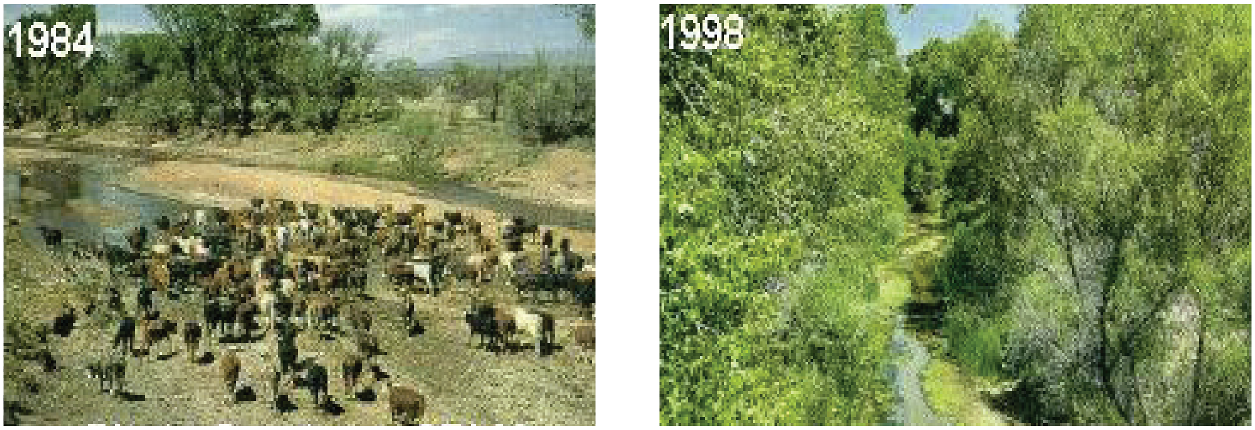


**Figure 2.** View from Hereford Bridge of the SPRNCA pre (1984) and post (1998) cattle with removal (Courtesy of Bureau of Land Management).

and amphibians, and 100 species of breeding birds. It also provides significant habitat for 250 species of migrant and wintering birds and contains archaeological sites representing the remains of human occupation from 13,000 years ago (Tellman and Huckleberry 2009).

Extensive human use of dryland rivers has resulted in many changes to their biota. For example, in parts of the San Pedro River Region, ground water depletion and overgrazing by livestock have contributed to shifts from cottonwood-willow (*Populus-Salix*) forests to *Tamarix* shrub lands (Stromberg 1998, Lite and Stromberg 2005).

As part of the formation of the SPRNCA, cattle grazing in and around the floodplain of the Upper San Pedro River was prohibited. Figure 2 is a picture of the Upper San Pedro from the Hereford Bridge in 1984 and in 1998 (10 years after the cattle were removed). As can be seen in the figure, the removal of cattle from the SPRNCA resulted in restoration of herbaceous riparian vegetation and a narrowing and stabilization of the river channel. In a recent study of the effects of cattle removal in the SPRNCA, Kruper et al. (2003) found dramatic increases in abundances of breeding and migratory bird species in the years following cattle removal that they attributed to increased vegetation volume, particularly in the herbaceous ground-layer.

With the SPRNCA having been passively restored from overgrazing following removal of livestock, the question now confronting policy makers is how to preserve this diverse ecosystem. Climatic and anthropogenic changes pose threats to the continued preservation of the SPRNCA. Figure 3 details the magnitude of the task beyond removing cattle (Kreuper et al. 2003). In the left-hand portion of the figure, the "status quo" is projected to lead to a reduction in the aquifer storage levels and in the right-hand portion, consumptive use of water resources will increase over time due to continued ground water pumping to support municipal, industrial, residential, and agricultural activities (Pool and Coes 1999, Pool and Dickinson 2007, Leake et al. 2008).

## Decision Support System

A significant research effort has been directed at understanding the impacts of ground water pumping on the SPRNCA biota and developing policy options that could be used to mitigate its impacts (Leenhouts et al. 2006, Pool and Dickinson 2007, Leake et al. 2008). An up-to-date ground water flow model (Pool and Dickinson 2007) and decision support system have been developed with the aid of systems dynamic modeling software (Yalcin and Lansey 2004) by the Upper San Pedro Partnership. These tools provide the basis for understanding the impacts of alternative policy decisions and identifying the effectiveness of alternative water conservation measures for the Sierra Vista Sub-basin of the Upper San Pedro (Sumer and Lansey 2004, Richter 2006).

The ground water flow model is a 3-D numerical representation of the aquifer in which the effects of pumping or recharge at one or more locations can be predicted at other locations. However, to run multi-decade simulations with this ground water model requires significant experience and computational

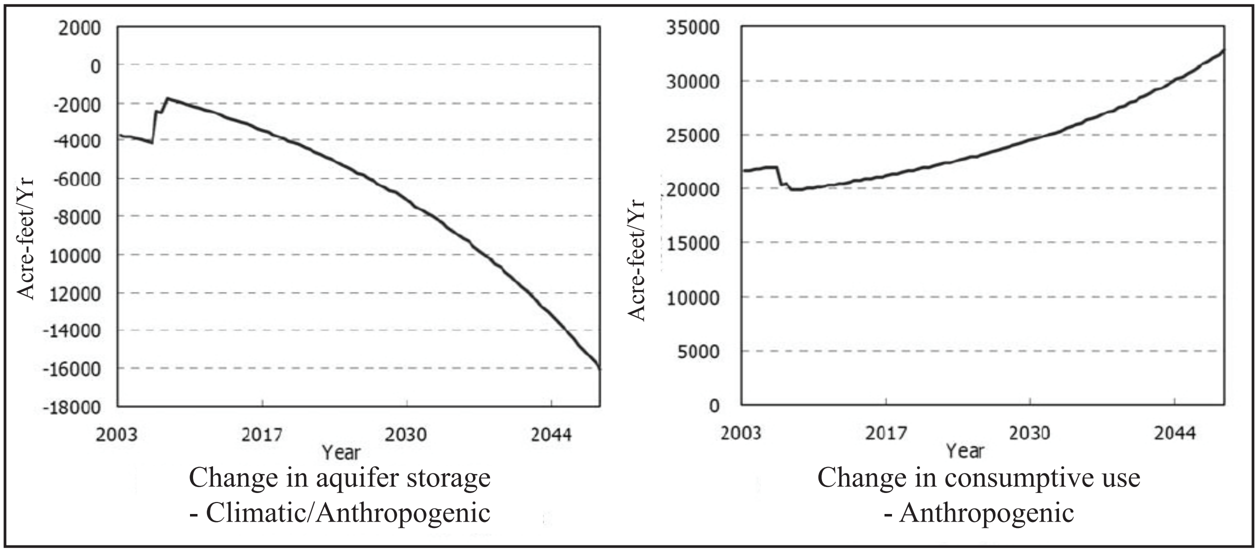


**Figure 3.** Projected Climatic and Anthropogenic Impacts on the SPRNCA.

time and is not suitable for incorporation into the Decision Support System for rapid assessment of a myriad of policy options by resource managers and decision-makers who do not have modeling expertise. Therefore, the decision support system model was designed to run rapidly and mimic the predictions of the ground water model. This was accomplished by running the ground water off-line to develop unit response functions between user specified pumping or recharge locations and locations of interest such as along the riparian area.

The decision support system allows future conditions (scenarios) to be analyzed that represent alternative decisions and anthropogenic impacts. The scenarios were derived using a variety of adjustments within the decision support system. Population growth rates can be changed differentially in four incorporated areas and three unincorporated areas (Figure 4a). Posited water importation amounts via an extension of the

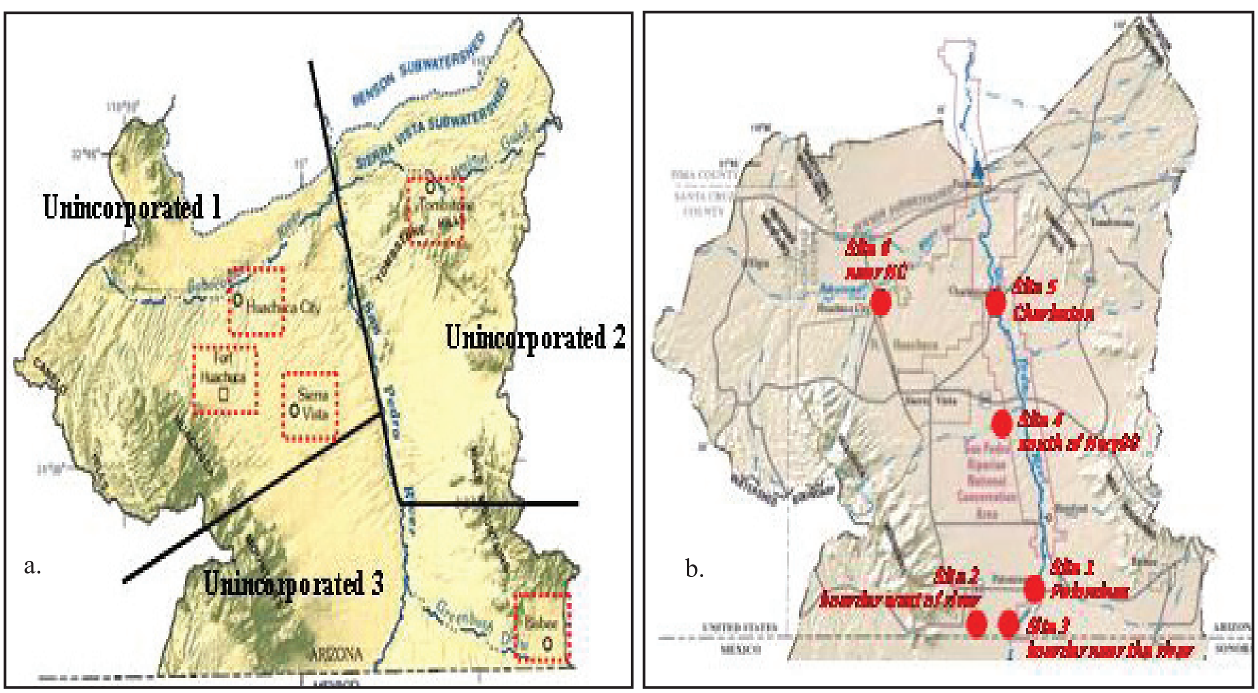


**Figure 4.** a. Cities and unincorporated areas in the Sierra Vista sub-watershed of the San Pedro. b. Six USPP identified potential recharge sites.

Central Arizona Project can be varied with different combinations of Central Arizona Project excess water recharged in multiple locations (Figure 4b). Large-scale rainwater harvesting in the City of Sierra Vista can be implemented; pumping and recharge amounts for Whetstone and Tombstone sites can be altered and the acres of irrigated agricultural can be varied. The decision support system model, as configured, evaluates conditions from 2002 to 2048.

Nine policy scenarios, differing from the current conditions case, were established by varying combinations of the above factors in the decision support system which resulted in the following nine ground water futures.

1. *Ground Water Future 1:* 0.5 m uniform decline in ground water table.
2. *Ground Water Future 2:* 1 m uniform decline in ground water table.
3. *Ground Water Future 3:* 0.5 m uniform increase in ground water table.
4. *Ground Water Future 4:* Continued and increased agricultural pumping near Palominas; new developments in unincorporated areas of Palominas and Hereford near SPRNCA.
5. *Ground Water Future 5:* Increasing cone of depression in Sierra Vista, Ft. Huachuca, and Huachuca City with impacts toward the lower Babocomari and northern SPRNCA.
6. *Ground Water Future 6:* Large increases in groundwater levels due to recharge and conservation efforts in Sierra Vista and Bisbee.
7. *Ground Water Future 7:* Combined from scenarios 4 & 5, representing effects of both agricultural pumping in the south and increasing cone of depression.
8. *Ground Water Future 8:* Low extreme - river essentially dries up.
9. *Ground Water Future 9:* High extreme - river essentially has surface flows throughout SPRNCA.

Within the coupled model framework of the decision support system, changes of ground water hydrology (e.g., changes in ground water levels relative to the channel) resource levels cause (Figure 1 - Box 4) changes in overall vegetation patterns (Figure 1 - Box 5). Our interest lies in the predicted changes in the vegetation classes in the system.

Based on research from project ecologists, river reaches were classified into one of three types (condition classes): Wet, Intermediate, Dry. The condition classes are based upon nine types of plants that are sensitive to changes in the hydrologic regime. This classification reflects variables such as annual surface water permanence, depth to ground water, and vegetation composition (Lite and Stromberg 2005, Stromberg et al. 2007). Thus, each of the condition classes represents a different level of ecosystem functional capacity as driven by the hydrologic regime. Currently, the SPRNCA consists primarily of Wet and Intermediate reaches. Under current conditions, the Dry condition class is primarily tamarisk (73 percent) and cottonwood (10 percent). The Intermediate reaches are approximately 21 percent tamarisk and 63 percent cottonwood and the Wet reaches have little or no tamarisk and 98 percent cottonwood.

Figure 5 depicts the current condition of the river reaches and the predicted condition classes for the nine policy driven ground water futures. Ground Water Futures 8 and 9 represent the extreme of the possible outcomes in SPRNCA. These are the situations where the Wet condition class is dominant (GWF 9) and where the Dry condition class is dominant (GWF 8). The importance of the intermediate outcomes lies in the illustration of how different policy futures/scenarios may affect the riparian areas.

The change in the composition of vegetation leads to a change in the abundance of breeding and migratory birds throughout the SPRNCA (Figure 1 - Box 6). Certain guilds within the avian community are strongly affected by the hydrologic regime and resulting vegetation composition, such as wading and canopy nesting birds (Brand et al. in revision). Figure 6 illustrates the changes in avian populations as a result of the changes in the hydrologic regime and vegetation changes found in Figure 5.

For example, in Figure 6, a 0.5 or 1.0 m meter uniform decline as represented by GWF 1 or GWF 2, respectively, would be expected to lead to declines in average migratory bird abundance within the study area compared with current conditions or the recharge scenario GWF 3 (Brand et al. in preparation).

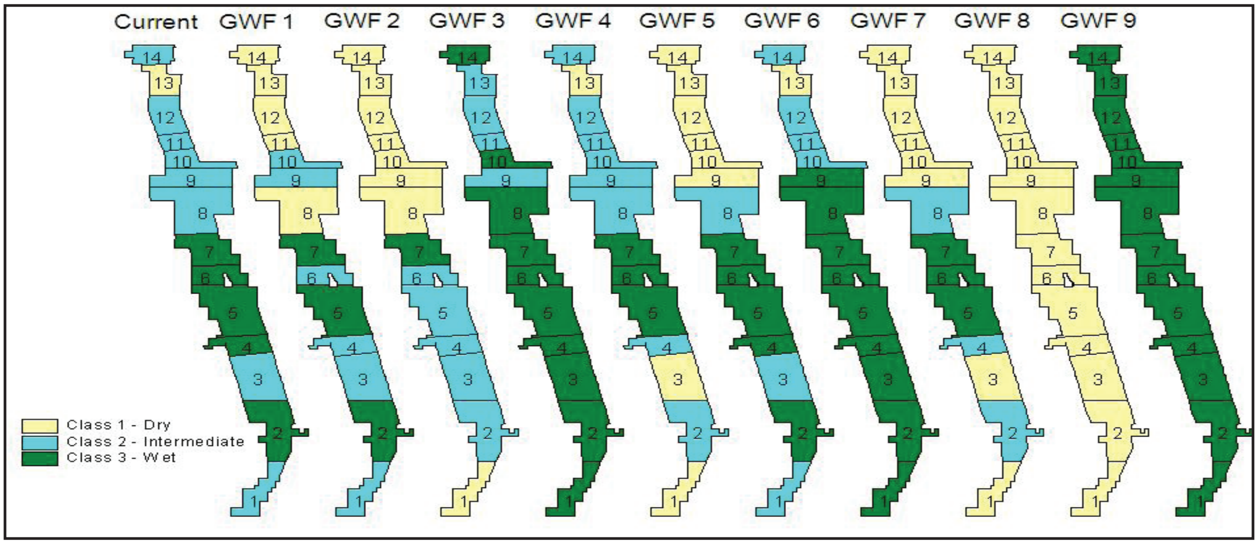


**Figure 5.** Nine hydrologic scenarios and the current conditions for the SPRNCA.

## Valuing Ecosystem Services Attribute Bundles

Linking the Decision Support System with the physical and natural science disciplines generates ecosystem attribute bundles (e.g., vegetation composition, water availability, breeding, and migratory bird abundances). Using these, the social scientist is left to decide how to obtain economic values for these alternative bundles. Currently, two stated preference techniques for conducting ecosystem services valuation have undergone significant development in the economics literature: Contingent Valuation and Choice Modeling.

CM, a variant of conjoint analysis, in its simplest form elicits an individual's preferences by asking the subject to consider current conditions as represented by a bundle of specific ecosystem service attributes relative to an alternative bundle. This decision process is repeated multiple times. From this information the researcher may infer the marginal value (i.e., the value associated with the ecosystem attribute) for the various ecosystem attributes individually. Contingent Valuation, on the other hand, asks individuals to explicitly state their willingness to pay for a proposed change in a single ecosystem attribute. Both Contingent Valuation and Choice Modeling models utilize a random-utility framework to explain individuals' preferences for alternative profiles and are directly estimable from the Contingent Valuation and Choice Modeling data.

The outcome of these approaches will yield marginal dollar values for changes in: miles of surface of water, breeding birds by nest height, breeding birds by surface water dependency, spring migratory birds, and alternative condition class vegetation options.

## History of Research within the Upper San Pedro Basin

A research record spanning over 50 years provides a substantial scientific foundation that underpins this particular effort. Multiple agencies, universities, and investigators have participated over the years in developing the underlying scientific understanding that enabled the development of the DSS and thus the inputs to the effort to place values on ecosystems services. Much of the early (and continuing) research has been centered on the U.S. Department of Agriculture–Agricultural Research Service's (USDA-ARS) Walnut Gulch Experimental Watershed, a sub-watershed within the Upper San Pedro River Basin (Moran et al. 2008). The Walnut Gulch Experimental Watershed is arguably the most densely instrumented and well-researched semiarid watershed in the world. It was established in the mid-1950's to conduct basic arid and semiarid hydrologic watershed research. An initial objective was to quantify the influence of upland conservation on downstream water supply to help understand and resolve conflicts arising from prior appropriation water laws. Early

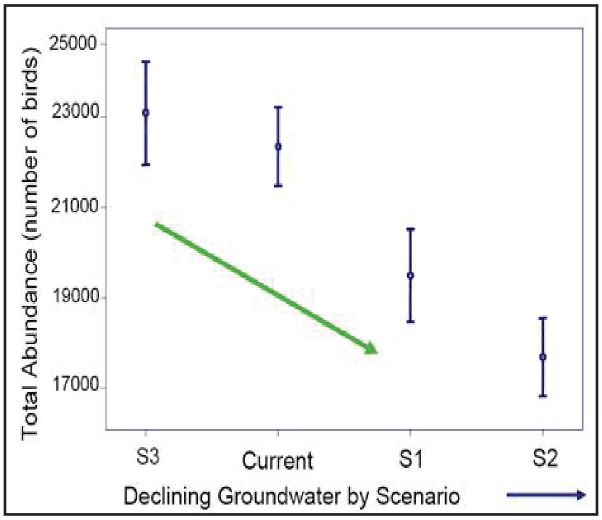


**Figure 6.** Migrating bird abundance changes and standard errors.

research focused largely on the abiotic aspects of watershed characterization, process understanding, and watershed response. The knowledge base, long-term databases, and substantial infrastructure of the Walnut Gulch Experimental Watershed served as a magnet for collaborative efforts with other Federal and state agencies, universities, and foreign researchers.

More integrative, multidisciplinary land-atmosphere, and remote sensing research was initiated as part of the MONSOON'90 (Kustas and Goodrich 1994) and "Walnut Gulch '92" (Moran et al. 1993) experimental campaigns. The core group of researchers from these projects formulated the SALSA (Semi-Arid Land-Surface-Atmosphere) Research Program to expand efforts into the Upper San Pedro River Basin in both the U.S. and Mexico (Goodrich et al. 2000) to move to larger spatial scales and a greater diversity of disciplines to more directly address semiarid global change research challenges. The SALSA Program (1995–2000) brought together scientists from 20 U.S., five European, and three Mexican agencies and institutions and expanded the range of disciplines contributing to investigations to include ecology, biology, isotopic ecohydrology, and geophysics and initiated much more direct interaction with watershed managers, decision-makers, and the public to focus current research onto pressing basin needs (Chehbouni et al. 2000, Brady et al. 2000).

In 1998, the Upper San Pedro Partnership was formed, which included the USDA-ARS as a member of the SALSA Research Program lead group. This development brought the integration of science with policy and decision-making squarely to the fore with water as a central focus and preservation of the ecological function of SPRNCA as a central goal. Science-based decision-making is a key tenet of the Upper San Pedro Partnership and they have made significant investments in research above and beyond those already noted. In 2000, the University of Arizona was awarded a NSF Science and Technology Center grant named SAHRA for "Sustainability of semi-Arid Hydrology and Riparian Areas." The mission of this 10-year, $30 million plus research enterprise is to identify critical stakeholder-relevant knowledge gaps and conduct basin-focused multidisciplinary research to fill them and to convey what is known and what is being learned to improve water management and policy. It was a natural fit for SAHRA to select the San Pedro as one of its focus basins and to begin working closely with the Upper San Pedro Partnership shortly after its establishment. Much of the research initiated in SALSA has been continued and expanded via SAHRA. SAHRA resources enabled more disciplines to be added to the San Pedro effort bringing in economists and social scientists with a strong education and outreach component which also led to the formation of the team conducting the study described herein.

## Can Ecosystem Service Values Be Robust across Alternative Semi-Arid Riparian Areas?

It is recognized that the circumstances that resulted in the exceptional scientific foundation and integration with the policy and decision makers within the San Pedro is quite unique and would be difficult to replicate in other areas or watersheds. The San Pedro characterization of research or a decision-maker enterprise took much more time than a three-year grant cycle or five-year agency planning cycle, and it could not have been accomplished by a single agency or university. However, we can capitalize on this exceptional foundation to develop a very high standard for science-based ecosystem valuation. We can then test the transferability of San Pedro results to other areas. This will allow us to quantify the level of ecosystem valuation that can be done in locations that have garnered less funding but have similar issues and characteristics (e.g., semi-arid riparian areas).

The Middle Rio Grande in New Mexico is one such example of issues of declining water supplies and resulting changes in vegetation and bird communities.[2] Beyond the question of determining the ecosystem values for certain services in the SPRNCA area, this research effort is addressing the same questions of value determination in the Middle Rio Grande. More specifically, we are interested in the robustness of the relative ecosystem values of the two sites: SPRNCA and the Middle Rio Grande. That is, can the ecosystem values measured for one site be transferred to another site? The importance of this issue lies in the possibility of extending the SPRNCA ecosystem values to a larger area than just the SPRNCA per se or even other areas in the Southwest.

The use of benefit transfer studies has been growing over the years, not only as a recognition that original studies cannot be done in all locations due to their high cost, but also from the required expanded use of benefit cost analysis by governmental organizations (Brookshire and Neil 1992, Desvousges et al. 1998, Brookshire and Chermak 2007, Brookshire et al. 2007).

Most of the literature on benefit transfers has relied upon science as a given in the valuation process (Desvousges et al. 1998). We seek to expand this discussion to consider issues of how the science should be organized in generating the ecosystem attribute bundles for valuation purposes.

In determining the attribute bundles for valuing the ecosystem services of the SPRNCA and Middle Rio Grande there are four possible methods that could have been utilized:

1. *Focus only on the SPRNCA ecosystem:* This valuation process would use the best available science information to uniquely reflect the attributes in the SPRNCA. Consideration would not be given in the design to the issues associated with transferring the valuation results to other semi-arid riparian areas. This would lead to a traditional benefit transfer exercise where the transfer is only a "rough" fit with regards to the attributes.
2. *Focus only on an alternative ecosystem (the Middle Rio Grande, NM):* The valuation process would use the best available science information to uniquely reflect the attributes of this system. Consideration would not be given in the design to the issues associated with transferring the valuation results to other semi-arid riparian areas. Again, this would lead to a traditional benefit transfer exercise.
3. *Design the valuation instruments with the SPRNCA as a base*, attempting to account for the disparity in scientific information between the SPRNCA and an alternative ecosystem (the Middle Rio Grande, NM) (e.g., differences in types and amounts of scientific information and differences in the ecosystems themselves including the different species assemblages found in the two areas): This would engender a more robust set of benefit transfer exercises.
4. *Design the valuation instruments in tandem,* with the goal of creating a set of ecosystem values that are transferable to most semi-arid regions in the Southwest.

Depending on the goal desired, one would follow a different process, where the results of each goal may be in conflict with each other. Below we outline in more detail the oppositional nature of these goals.

In defining the attributes to be valued, one key problem is how to represent the complex ecological processes and outputs, many of which are inherent to particular locations. For instance, in developing the SPRNCA condition class model, nine different riparian vegetation attributes are measured (Stromberg et al. 2007, Lite and Stromberg 2005) where only four vegetation attributes are to be represented in the survey. Likewise the avian modeling for the San Pedro estimated over thirty possible single-species and twelve grouped-species abundance attributes for breeding and migratory birds, as well as species richness and nest success, with only three attributes being used in the ecological valuation study. Clearly the level of detail normally addressed by science goes far beyond the cognitive burden of survey respondents. Additionally, there is no assurance that the scientific attributes selected for the San Pedro will apply as well to other study areas. Structuring and simplifying the science inputs from the ecologic models across locations requires an iterative and multi-pronged process.

### Goal 1: Focus Only on the SPRNCA Ecosystem

The key physical driver in the SPRNCA is the availability of surface and ground water. Ground water pumping in concert with natural variations in stream hydrogeomorphology creates gradients of depth to ground water along the river. The riparian vegetation responds to these changes in surface and ground water resulting in a change in the composition of riparian vegetation. To best represent this, changes in vegetation attributes would need to be presented for each river reach in terms of:

1. Abundance of tall, flood-dependent, wetland trees (i.e., Fremont cottonwood and Goodding willow);
2. Abundance of short, flood-dependent, drought-tolerant shrubs (i.e., tamarisk); and
3. Abundance of wetland ground cover and stream surface water.

Riparian birds respond to both the physical change of surface and ground water and the change in the vegetation composition, resulting in a change in bird species composition and abundance. For example, Brand et al. (in review) found that canopy nesting birds had lower abundances in salt cedar compared with tall trees on the SPRNCA associated with the transition of wet or intermediate reaches to dry reaches. That study also found that water obligate birds (e.g., wading, swimming, or shorebirds) had lower abundances in intermediate or dry condition classes compared with perennial flow. It was also hypothesized that migrating birds would decrease in abundance in drier reaches thought to harbor less insect prey. To best represent these expected changes, bird attributes would need to be presented in terms of:

1. Abundance of canopy vs. non-canopy nesting birds;
2. Abundance of water-dependent birds; and
3. Abundance of migrating birds.

### Goal 2: Focus Only on an Alternative Ecosystem (the Middle Rio Grande, NM)

The key physical driver in the Middle Rio Grande is the alteration of the flood disturbance regime. Secondarily, human restoration actions drive change, where changes in the system have occurred as a result of channelization, land clearing, agricultural use, wildfire control, and urban use. As a result of the reduction in river flooding caused by dam management, the species composition of the riparian vegetation has changed and the density of the vegetation has increased. Some parts of the floodplain support tall, old, flood-dependent cottonwood forests with a very dense understory of smaller, flood-intolerant trees. Some of the understory trees are introduced species (such as Russian olive); others are native (such as New Mexico olive). As a result of changes in the pattern of river flooding (and perhaps in water-table depth), other parts of the floodplain no longer support cottonwood but support dense stands of the shrub salt cedar. Restoration actions are shaping the vegetation by mechanically clearing non-native plants in the dense mid-story vegetation. To characterize these changes, the information would be presented in terms of:

1. Abundance of tall, flood-dependent, wetland trees (i.e., Fremont cottonwood and Goodding willow);
2. Abundance of short, flood-intolerant trees.
   a. native
   b. introduced; and
3. Abundance of short, flood-dependent, drought-tolerant shrubs (i.e., tamarisk).

As a result of changing vegetation, riparian birds change in terms of composition and abundance. For example, mid-story and possibly understory nesting birds would be predicted to decrease in abundance with mechanical thinning of the non-native understory. Migrating birds could also decrease in abundance due to decreased vegetation volume or lower insect prey. To characterize these changes, information should be presented in terms of:

1. Abundance of canopy, mid-story, and understory nesting birds; and
2. Abundance of migrating birds.

The distinct physical differences and anthropogenic pressures between the alternative ecosystem (the Middle Rio Grande, NM) and the SPRNCA illustrate that goals 1 and 2 would lead to a different set of vegetation and bird attributes if each site were considered individually. For example, we did not expect strong effects on water-obligate birds since the surface water regime was expected to stay more constant across scenarios on the Middle Rio Grande, in contrast with the SPRNCA. The different attributes demonstrate how different physical and anthropogenic drivers on the two river systems (alteration of ground water regime on the SPRNCA; active mechanical thinning and lack of flooding on the Middle Rio Grande) impact the ecosystem attributes.

## Goal 3: Create a Set of Ecosystem Values Transferable across the SPRNCA and Middle Rio Grande

Ground water and flood regimes are two key driving variables that structure dryland riparian ecosystems across the SPRNCA and Middle Rio Grande river systems, while mechanical thinning of understory vegetation ("restoration") is an important physical driver for the Middle Rio Grande. To capture the effects of changes in these master variables on riparian vegetation of unconstrained, low gradient, historically perennial rivers of the American Southwest, information could be presented for each river reach on:

1. Abundance of tall, flood-dependent wetland tree species (e.g., Fremont cottonwood, Goodding willow);
2. Abundance of short, flood-dependent drought-tolerant shrub species (e.g., tamarisk);
3. Abundance of short, flood-intolerant trees (e.g., Russian olive, velvet mesquite); and
4. Abundance of herbaceous wetland vegetation and surface water.

The key variables that are driving changes on SPRNCA and/or Middle Rio Grande bird communities are the availability and composition of riparian vegetation and surface water. To capture these more general influences, information should be presented on the union of attributes from the SPRNCA and Middle Rio Grande:

1. Abundance of canopy, mid-story, and understory nesting birds;
2. Abundance of water dependent birds; and
3. Abundance of migratory birds.

The distinction between goals 1 or 2 with goal 3 shows that the set of vegetation and bird attributes would need to be the union, or combination, of attributes for the two individual river systems. For example, characterizing birds on the basis of three nest height classes on both rivers should enable us to isolate bird groups sensitive to changes on the SPRNCA (e.g., canopy nesting birds) and on the Middle Rio Grande (e.g., midstory nesting birds). If each site were considered individually it would be important to have the set of attributes that best represented the specific physical drivers occurring on that river system.

## Goal 4: Create a Set of Ecosystem Values Transferable across Southwestern Riparian Systems

There are many key variables that shape semi-arid riparian areas in the Southwestern U.S., such as hydrologic regimes (ground water flows, base flows, flood flows) and geomorphic regimes (sediment flows and other geomorphic processes). Other key drivers include water quality (including salinity and nutrients), fire, climate, and activities of mammals including beavers (an ecosystem engineer), large herbivores, and people (including restoration actions). The approach would need to quantify ecosystem response to the wide range of flow regimes (ephemeral, intermittent, perennial), watershed sizes and stream orders (flood magnitude), stream geomorphologies (stream gradient, floodplain width), elevations and geographic locations found throughout the region. A taxonomy of the major types of human actions that can alter riparian areas in the Southwest would be needed to pursue this approach. This taxonomy of human actions would then be used to create riparian vegetation responses and changes in bird abundances. Implementation of this goal would require the development of some sort of index to predict what is going on in a new river system without conducting significant research and collecting a lot of additional system characterization data.

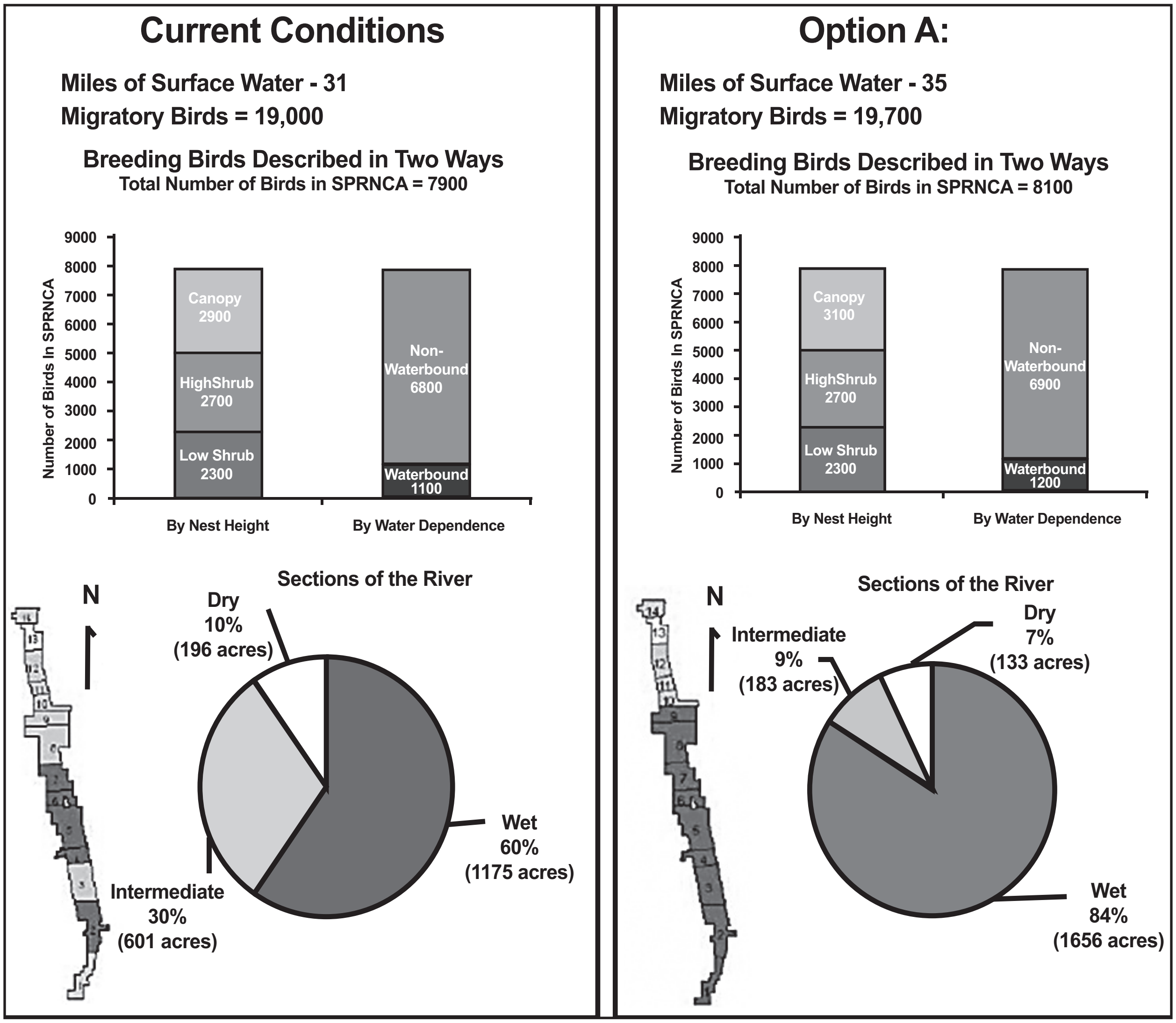


**Figure 7.** Example of a Choice Modeling question in the "coarse" survey.

## The Surveys: A Brief Summary

Our path has been Goal 3. That is, we have focused on the development of the surveys using the best science available from the SPRNCA and using that as a basis to inform the science for the Middle Rio Grande. Four surveys are currently being administered: 1) SPRNCA - Choice Modeling, 2) SPRNCA - contingent caluation, 3) Middle Rio Grande - choice modeling, and 4) Middle Rio Grande – contingent valuation. The surveys were developed with the help of the scientists on the project in order to maintain the scientific accuracy of the survey information and by focus groups.

The structure of the "Coarse" SPRNCA choice modeling and the contingent valuation survey have the following components: (The Middle Rio Grande surveys are similar.)

1. Introduction and discussion of the importance of riparian zones;
2. Background information of three important characteristics of the SPRNCA;
3. Discussion of water (focusing on surface and ground water interactions), vegetation (focusing on types and relationships to water availability) and birds (focusing on types and relationship to vegetation cover);
4. Current conditions for the three riparian condition classes;
5. Relevant policy measures (appropriate variations for contingent valuation);
6. Choice or dichotomous questions (appropriate

variations for contingent valuation); and

7. Socioeconomic activity information.

Respondents are presented with a summary of each of the current condition classes, and provided with information about the average surface flow and density of birds by type (Figure 7). The appropriate question structure is then asked of the respondents depending on whether it is a choice modeling or contingent valuation survey. The surveys are Internet based with follow-up mail surveys, if necessary. The sample pool is a random sample of households within 800 miles of the SPRNCA.

The results will provide the marginal dollar values for changes in: 1) miles of surface water, 2) abundance of breeding birds by nest height, 3) breeding birds by surface water dependency, and 4) spring migratory birds and vegetation condition classes.

## Summary

Conservation of fresh water systems will continue to be a critical issue in the semi-arid Southwestern U.S. Integrating the vast amount of scientific knowledge of these fresh water systems into a survey to determine ecosystem values can help policy makers as they prepare to preserve diverse ecosystems through reallocation of existing water resources. The SPRNCA research efforts are an example of a Southwestern ecosystem that has shown great promise in integrating science and policy goals.

Just as the coupling of the science models allows for an evaluation of water supply alternatives, the integration into the decision support system of the ecosystem values will allow for evaluation of more detailed and robust scenarios. The scenarios that could then be considered would move beyond basic planning efforts (e.g., where to allow wells and recharge basins) to formally integrate behavioral relationships. Thus, a variety of behavioral incentives, such as urban water use pricing schemes, could then be explored and the evaluation would draw directly upon the underlying ecosystem values as various tradeoffs were made.

## End Notes

1. The Upper San Pedro Partnership (USPP - http://www.usppartnership.com) is a consortium of 21 NGO's, a private water company, and local, state, and Federal agencies (Richter et al. 2009) that is working to maintain sufficient water for the basin's citizens and a functioning riparian ecosystem in the San Pedro National Riparian Conservation Area (SPRNCA) through conservation and augmentation projects.
2. We refer to the Middle Rio Grande as roughly being from Cochiti Dam to Socorro, NM. Our actual study area is within its boundaries from Corrales to Bernardo.

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